EXPERIMENTS WITH A FREE FLOATING WAVE BUOY

by

Albert J. R. Galus

United States
Naval Postgraduate School

THESIS

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Albert J. R. Galus
Lieutenant (junior grade), United States Navy
B.S., United States Naval Academy, 1969

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ABSTRACT

A free-floating wave meter was used to obtain a time series of wave-induced pressure variations in deep water. The meter's response was roughly checked against a piston-type pressure testing apparatus.

Techniques in the operation of the meter were developed involving a slight modification in the suspension of the sensor.

Power spectra of the pressure variations were obtained from the digitized wave record via the amplitude spectra given by the fast Fourier transform.

Characteristics of the power spectra of the metered waves were used to evaluate the meter by comparing them with the waves that might be anticipated (on the basis of theory) from the existing surface wind field and with visual observations of the metered waves.

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ACKNOWLEDGEMENTS

The author would like to express his appreciation for the advice and encouragement from Assoc. Professor J. B. Wickham. Lt. Thomas Lynch generously aided in the computer processing of the data used in this thesis. Finally, the author would like to express his gratitude to Fleet Numerical Weather Central for the use of their facilities.

I. OBJECTIVES

The U.S. Naval Postgraduate School acquired a free floating wave meter designed to measure deep water wind waves in the sea over the band of frequencies associated with swell and locally wind generated waves. It is desirable to make operational use of an instrument of this kind. Most wave metering requires a physically stable reference platform from which to record deep water wave activity, or it requires that the reference platform's motion be known. These tedious and expensive requirements are avoided with the free floating meter. In order to facilitate the use of this instrument in future research, the objectives of this paper are:

1. To estimate the response of the instrument by a direct calibration procedure;

2. To provide a detailed account of techniques and equipment used in making wave measurements at sea with the instrument;

3. To analyze the wave records and to compare the results with independent estimates of the wave parameters made for the same wave system.

II. THEORY

The free floating wave meter has a pressure sensor hung below a float which moves vertically with the free water surface.

The wave pressure for wave number, k, of the fixed depth z_1, is given by:

$$p_w(k;\ z_1,t) = p_o(k;t)e^{-kz_1}$$

where p_o is the static (or slowly time varying) component of the pressure due to the rise and fall of sea level.

For the bobbing meter suspended at the nominal (mean) depth, z_1, below the undisturbed sea surface, there are two components to the pressure variation: the dominant contribution is that due to the rise and fall of the sensor as the surface float is displaced, this being identically $-p_o(k,t)$, and the other is the change in environmental pressure p_w. Thus, the total pressure change experienced by the meter is approximately:

$$p_z(k;z_1,t) = -p_o(k;t) + p_o(k;t)e^{-kz_1}$$

$$p_z(k;z_1,t) = -p_o(1-e^{-kz_1})$$

Therefore, assuming that the sensor hangs vertically from the float, the instrument will detect pressure fluctuations corresponding to the vertical motion of the float.

If one wants to measure the sea surface displacement as indicated by the bobbing motion, the meter must be suspended at a sufficient depth z_1, such that:

$$p_z(k;z_1,t) \doteq -p_o(k;t)$$

That is, p_z accurately describes the surface wave action if $e^{-kz_1} \ll 1$ for wave numbers $k \geq k_o$. Letting $e^{-k_o z} = .1$ and $z = 300$ feet (the depth of suspension for the sensor in the measurement made in this study), pressure measurements from waves with wave numbers greater than .0077 feet^{-1}, or frequencies greater than .079 seconds^{-1} will not be in error by more than 10%. Gaul and Brown [1] give more detail in the theory of a free floating wave buoy.

III. DESCRIPTION OF THE INSTRUMENT SYSTEM

The instrument system has a transducer-buoy package, a signal conditioning deck unit, and recording units (Figure 1).

The transducer-buoy package (Figure 2) consists of a sensitive pressure transducer, small diameter (.060 in.) sea cable, and buoy hull, which contains a modulator, radio transmitter, batteries, and antenna. The transducer detects pressure changes by means of a vibrating wire whose frequency varies directly with the applied hydrostatic pressure. The sensitivity and frequency response are discussed in Section IV. The transducer and buoy electronics convert frequency changes into an FM signal with a center frequency of approximately 27 MHz. The components of this package are designed to minimize water and wind drag. The transducer has a streamlined torpedo shape of length 30 cm. and diameter 3 cm. The buoy is circular with a 60 cm. diameter in horizontal section, and has an elliptically shaped vertical cross-section of depth 14 cm.

The signal conditioning deck unit consists of a modified citizen's band radio receiver, a discriminator, a d.c. amplifier, and a band pass amplifier. The deck unit conditions the signal from the buoy so that a ten foot peak-to-peak wave results in a five volt peak-to-peak signal. The output signal does not represent absolute pressures; it reflects changes from the static pressure.

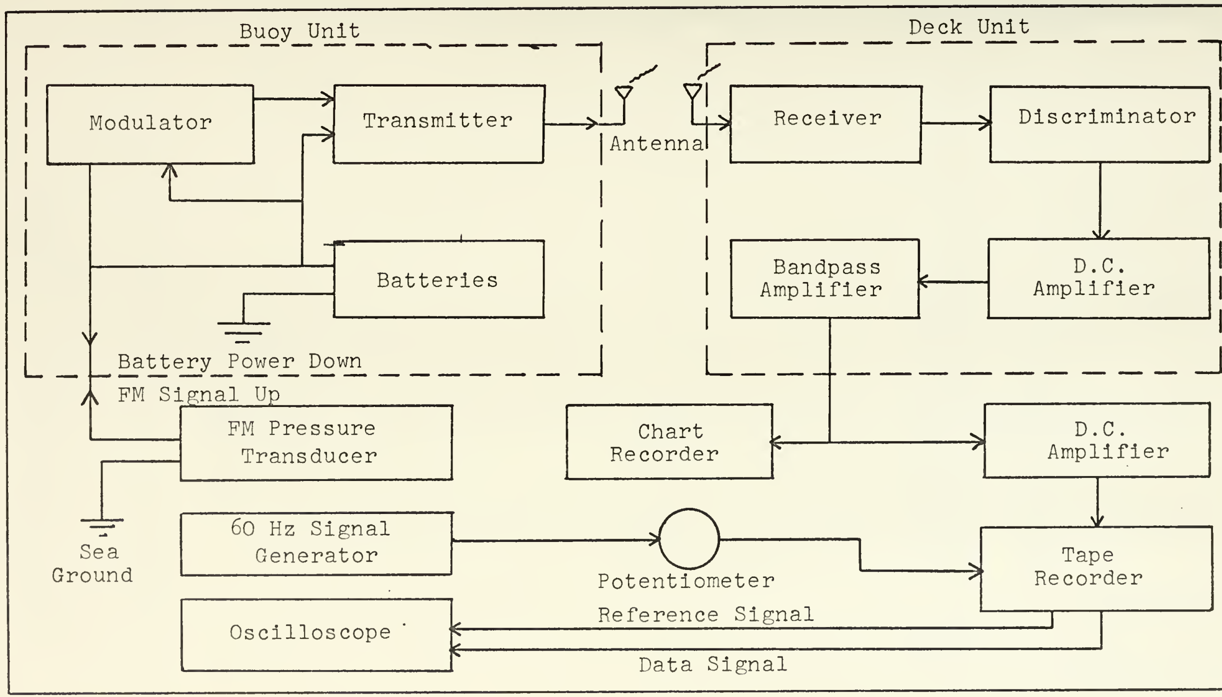

Figure 1. Instrument System

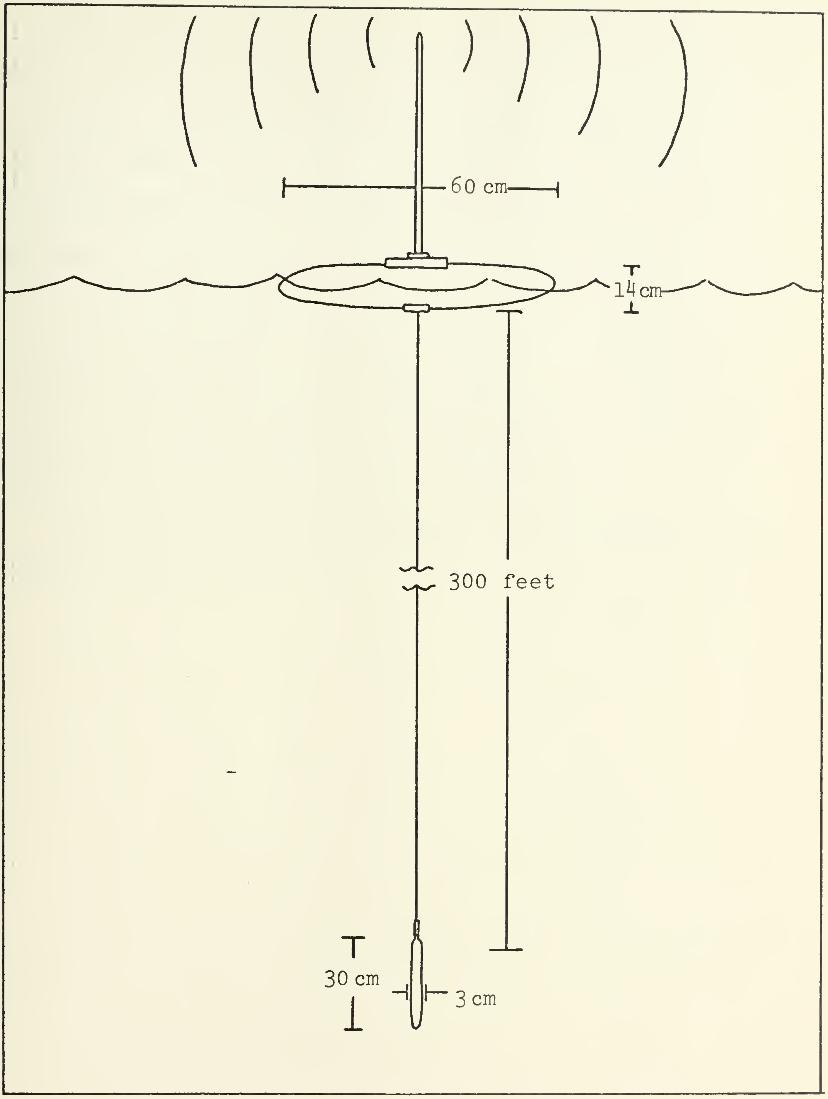

Figure 2. Transducer-buoy Package

The recording unit provided with the instrument is a Leeds & Northrup Speedomax H chart recorder. In addition to the chart recorder, the output signal from the deck unit was sent through a d.c. amplifier and recorded on a Sangamo 3500 14-track magnetic tape recorder. A signal generator was also used to put a 60 Hertz reference signal on a track other than the data track during the period of recording in order to identify the data to be processed. A double-beamed oscilloscope was linked to the playback outlets of the tape recorder in order to verify that the data and reference signal were being recorded.

More detailed information about the instrument can be found in Gaul and Brown [2].

IV. CHARACTERISTICS OF THE SYSTEM

This section discusses four characteristics of the instrument: frequency measurement limitations due to size of float, calibration dial characteristics, frequency response of the transducer-buoy electronics, and the response factor of the instrument.

A. FREQUENCY MEASUREMENT LIMITATIONS DUE TO SIZE OF FLOAT

The accuracy of pressure measurements, in part, depends upon the ability of the buoy to follow the surface of a wave. The buoy does not respond to waves with a length less than twice the diameter of the float (2.33 feet). Therefore, let the minimum observable wave length, L_o, equal 4.66 feet, and utilize the deep water equation

$$T = \sqrt{\frac{L_o}{5.12}} ,$$

where T is the period of the wave in seconds and L_o is in feet. From this equation, T is 0.954 seconds or frequency is 1.05 $\sec^{-1}$. Therefore, theoretically, the buoy does not respond fully to passing waves with frequencies greater than 1.05 $\sec^{-1}$ (i.e. $\sim$ 1 sec. waves).

B. CALIBRATION DIAL CHARACTERISTICS

The deck unit has a calibration dial used to maintain a 5 mvolt peak-to-peak output signal, which is equivalent to full scale deflection on the chart recorder for the same maximum wave height when the transducer is used at various

depths. For example, a dial setting of 500 when the transducer is at a depth of 300 feet gives a 5 mvolt peak-to-peak signal when a ten foot peak-to-peak wave passes. Figure 3 shows the dial setting for various depths to get full scale deflection for 10 foot waves. Figure 4 and 5 show dial settings vs. peak-to-peak voltages at constant depths for 10 foot waves.

C. FREQUENCY RESPONSE OF THE TRANSDUCER-BUOY ELECTRONICS

Table I on frequency response of the transducer-buoy electronics was obtained from the manufacturer of the system, Bissett-Berman Corporation, Hytech Marine Products. The table indicates that the pressure transducer is more responsive to pressure changes as the absolute pressure increases. By applying increments of pressure at various absolute pressures with a piston-type pressure gauge tester, it was concluded that the instrument does not record the magnitude of the pressure changes with sufficient sensitivity unless the absolute pressure is greater than 40 to 60 psi. Therefore, the instrument does not function properly in water with a depth less than 100 feet. This characteristic made it impossible to calibrate the meter by direct comparison with meters placed at near shore locations.

D. RESPONSE FACTOR OF THE INSTRUMENT

An attempt to compute the response factor of this instrument was made by obtaining power spectra of a known input and its response. The piston-type pressure gauge tester was

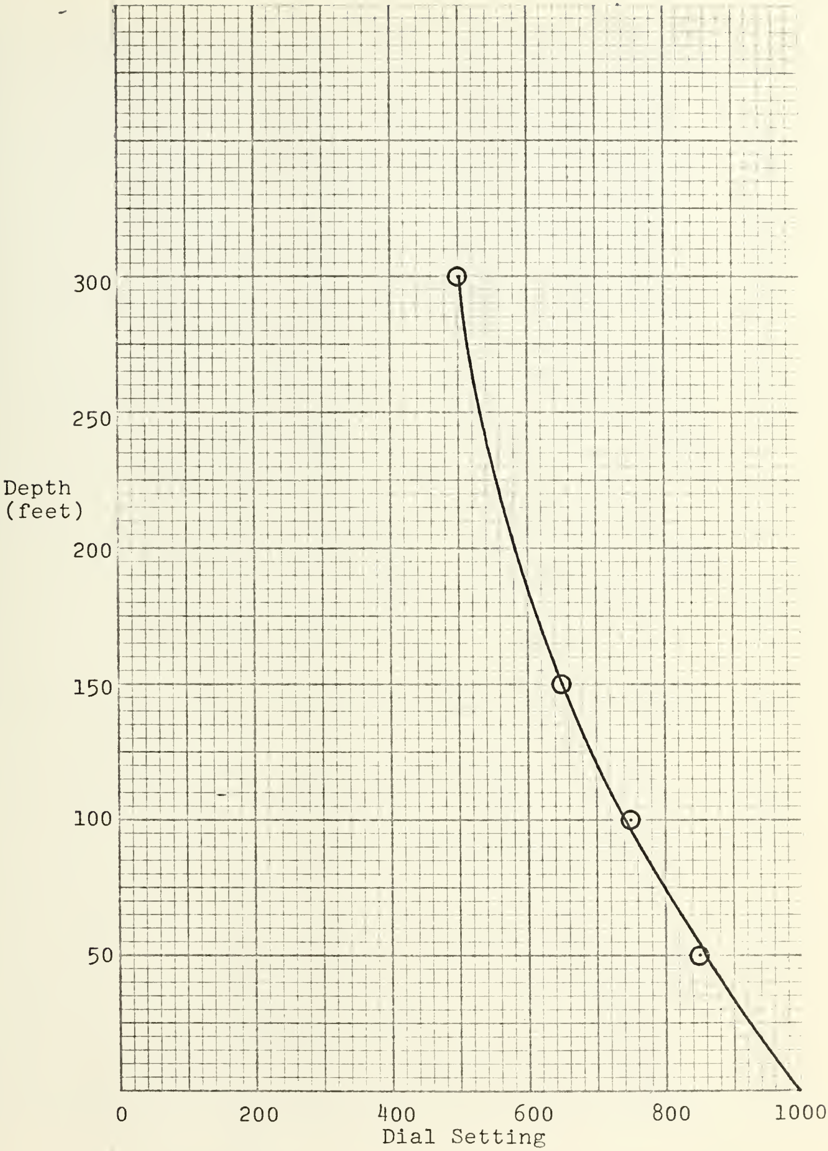

Figure 3. Depth vs. Dial Setting for 10 foot Wave

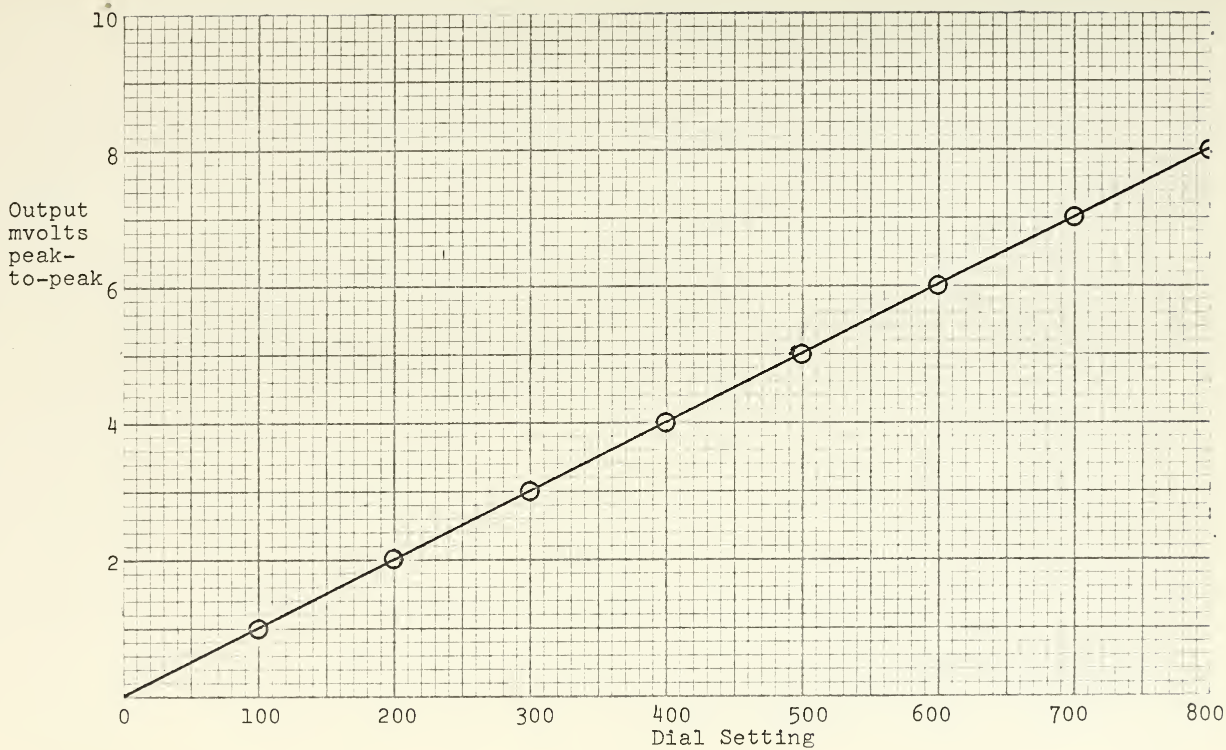

Figure 4. Output Voltage vs. Dial Setting at 300 feet for a 10 foot Wave

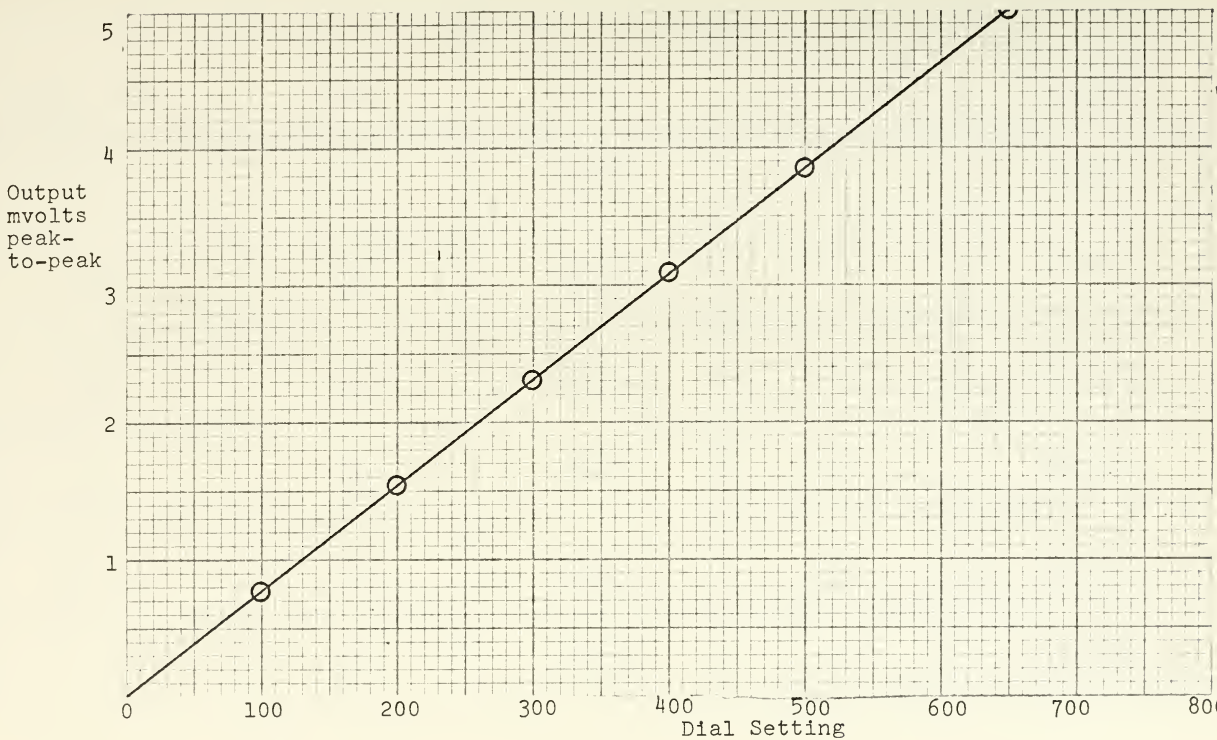

Figure 5. Output Voltage vs. Dial Setting at 150 feet for a 10 foot Wave

Depth (feet)	Pressure (psi)	Frequency (sec^{-1})	Δf for 2 psi Change (sec^{-1})	Δf for 10 foot Depth Change (sec^{-1})
50	21 23	1818.1 1807.3	10.8	23.868
100	43 45	1679.8 1667.9	11.9	26.299
150	65 67	1526.7 1513.3	13.4	29.614
200	87 89	1348.6 1333.7	14.9	32.929
245.45	107 109	1176.8 1160.9	15.9	35.139
300	131 133	980.3 964.3	16.0	35.360

TABLE I

FREQUENCY RESPONSE OF TRANSDUCER-BUOY ELECTRONICS

used to apply a 2 psi impulse over 2 seconds. After the impulse, the pressure was held steady for approximately 20 seconds.

Three separate trials were made for which the input, as constructed from visual readings of the pressure gauge and stopwatch dials, is essentially as shown in Figure 6. The power spectrum analysis of this input and the analyses from the three outputs are compared in Figure 7. Variations in the spectra of these three responses were due to the difficulties involved in creating three identical pressure impulses with the pressure gauge tester.

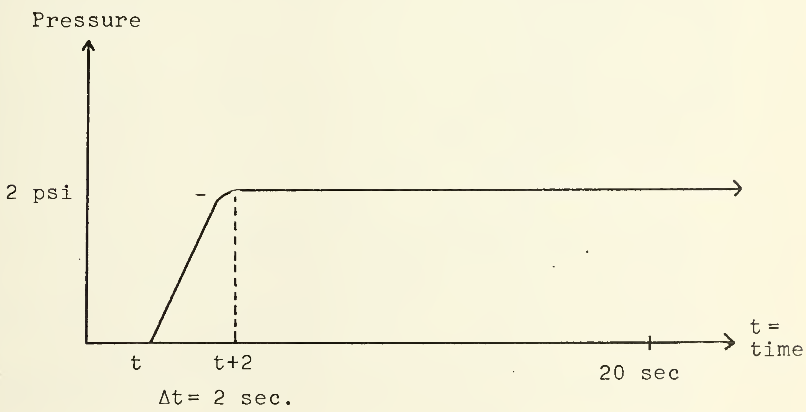

Figure 6. Input from Pressure Tester.

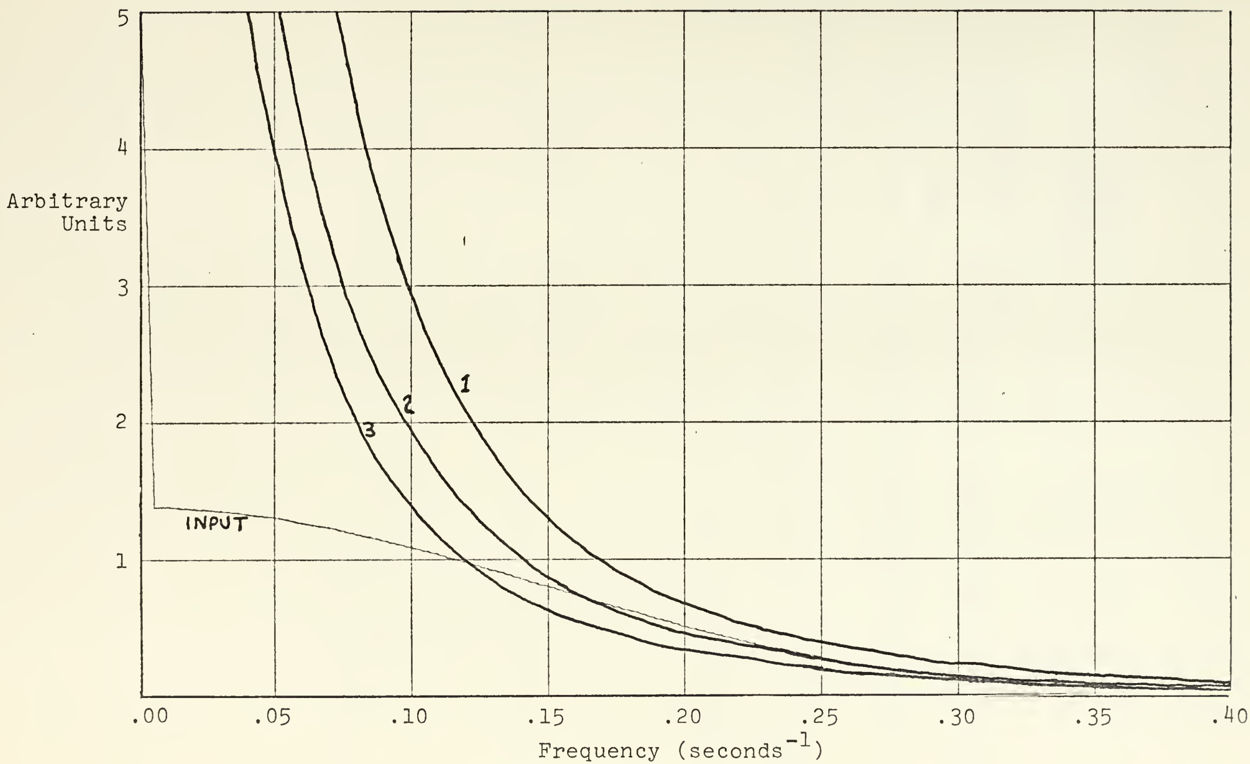

Figure 7. Spectra of Test Input and Responses 1, 2, and 3

The response factor was computed by the following formula:

$$R = \sqrt{\frac{AREA_{in}}{AREA_{out}}}$$

R = Response Factor

$Area_{in}$ = Area under input spectrum in stated frequency band

$Area_{out}$ = Area under response spectrum in same band

The results of this analysis were:

1. For frequencies greater than .15 sec^{-1}, the response factor was equal to 1.00.
2. For frequencies between .10 sec^{-1} and .15 sec^{-1}, the response factor was equal to 1.21.
3. For frequencies between .05 sec^{-1} and .10 sec^{-1}, the response factor was 1.63.

Therefore, these results suggest that the instrument over-responds to low frequency (.05-.10 sec^{-1}) waves. Frequencies less than .05 sec^{-1} were not considered because the instrument wasn't designed to measure frequencies that low. There is uncertainty in this analysis due to the uncertainty in the slope of the input pressure curve.

V. FIELD OPERATIONS

This section deals with the problems and techniques involved in handling the instrument system at sea.

The main difficulties at sea occurred in handling the sea cable. The sea cable has a tendency to coil and kink whenever it is not under tension. When a severe kink or puncture in the insulation occurs, the sea cable does not conduct the signal properly. Furthermore, the sea cable becomes difficult to handle when wet because of its small diameter. In addition to these problems, the 90 lb. test sea cable may snap with sudden jerks.

These problems were solved by taping a small diameter steel cable foot by foot to the sea cable. The rigidity of the steel cable prevents the sea cable from coiling and the tape enables the operator to get a good grip on the line. Furthermore, the steel cable increases the safety margin against losing the transducer.

The field operations described here were made from the U.S. Naval Postgraduate School's 63 foot oceanographic research boat. This boat is well-suited to operations involving this instrument because the launching and recovering of the buoy could be done by hand. A larger vessel would need a water level platform or smaller boat in order to handle the buoy easily. It would be difficult to use a hoist because of the delicate nature of the instrument and the large antenna mounted on top of the buoy.

In launching the floating package, the first step is to secure the buoy end of the safety line. With the boat engines stopped, the transducer and sea cable are then lowered in a hand-over-hand method, care being taken not to allow the sea cable to scrape against anything. This is best accomplished with the transducer lowered on the windward side of the boat. Then the sea cable and safety line are attached to the buoy, which is lowered by hand into the water. To obtain a vertical alignment with the transducer, the buoy is pulled away from the boat.

An audible tone from the receiver indicates that the system is in operation. It is recommended that the boat maintain a position 30 to 60 yards downwind from the buoy in order to insure strong reception of the buoy signal and to keep the buoy in sight. After the boat is in position and the equipment is functioning properly, the reference signal generator is turned on to indicate which portion of the magnetic tape has data to be processed.

The recovery of the buoy is similar to the launching operation. The buoy is easily brought aboard, by hand, with the base of the antenna serving as a handle. The sea cable and transducer are then hauled slowly aboard hand-over-hand.

These techniques for handling the instrument were satisfactory for waves as high as 12 feet with white caps present. For higher seas, different techniques in handling the instrument may be required.

Further detail of the operation of the instrument can be found in the Bissett-Berman Manual [3].

VI. RAW DATA

Four wave records were made under varying sea and wind conditions. All four records were made in an area centered 10 miles WNW of Monterey Harbor. All measurements were made in water with a depth in excess of 800 fathoms. Table II describes the characteristics associated with each wave record.

The Douglas Sea State Code taken from Fairbridge [4], describes codes 2, 3, and 4 (used in Table II) as follows:

State 2 ----- small wavelets, crests of glassy appearance, not breaking;

State 3 ----- large wavelets, crests begin to break, scattered whitecaps;

State 4 ----- moderate waves taking longer form, many whitecaps, some spray.

Run	Date	Duration (minutes)	Direction of Swell (degrees)	Recording Scale (feet)	Gain on Original Signal	Douglas Sea State	Wind Estimate (knots)
1	11 May	21.34	315	10	3000	3	7-10
2	20 May	22.25	310	20	10000	4	17-21
3	1 June	22.25	274	10	10000	2	4-6
4	2 June	22.25	300	10	10000	3	7-10

TABLE II

DATA CHARACTERISTICS

VII. DATA PROCESSING

Processing the data consisted of digitizing the wave record and obtaining a power spectrum.

Because of certain characteristics in the digitizing process, which will be explained later in this section, the data on the magnetic tape were played back at a speed of 60 ips (inches per second) (recording speed was 1 7/8 ips) through a chart recorder moving at a speed of 50 mm/sec. Furthermore, the data were played through a Khronhite filter, model 3321, with the cutoff frequency of 8 cps real time in order to get rid of noise introduced by electrical interference from the boat.

The wave records (Figure 8) were digitized using a Calma Company Model 480 Digitizer which records Δy (of the cartesian co-ordinates of the pressure curves) for every .01 inch of stylus travel in the x-direction. The digitized data were recorded on 5 inch mini-reels at 556 bytes per inch. In order to make the data compatible to the IBM 360, the record on the mini-reel was converted to punched cards by program "Convert" (see Appendix B) on the CDC 6500 at the Fleet Numerical Weather Central, Monterey, California. Because of a limited buffer capacity, program "Convert" is limited to 15000 sample points. Therefore, 150 inches is the maximum wave record length that can be processed. This was the reason for condensing the wave

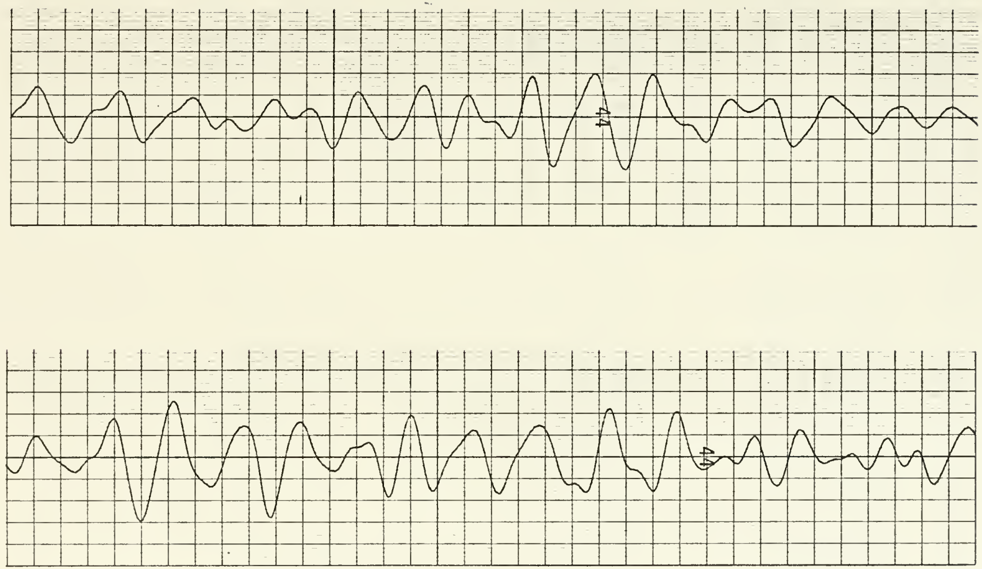

Figure 8. Filtered Wave Record (major division represents two feet)

record by playing back the data at a speed increased by a factor of 32 times the recording speed. Under these conditions, one second of real data was represented by 1.56 mm on the chart paper.

Due to the fixed sampling rate of the digitizer, the sampling interval, Δt, was .163 seconds. According to the Nyquist criterion, the maximum allowable Δt is:

$$\Delta t_{max} = \frac{1}{2f_{max}}$$

With f_{max} equal to 1.05 cps from Section IV, Δt_{max} = .476 seconds. Therefore, the actual sampling interval, .163 seconds, successfully meets the Nyquist criterion.

The power spectrum was obtained by utilizing IBM subroutine RHARM. This subroutine computes one-dimensional Fourier coefficients by using the fast Fourier transform. The power spectrum was smoothed over by averaging every 20 Fourier coefficients resulting in approximately 40 degrees of freedom. The entire procedure was performed by program "Spectrum" in Appendix B.

VIII. COMPARISON OF RESULTS WITH THEORETICAL WAVES

Figures 9-12 in Appendix A give the power spectra of the four records taken by the wave meter. These spectra were compared with visual observaitons and with waves expected from storm areas indicated by weather maps obtained from Fleet Numerical Weather Central.

Significant height estimates were obtained by observing by eye (with two different observers) and recording the vertical movement of the buoy from trough to crest of a large number of successive waves. The average of the highest one-third of these observations gives the significant height. From the power spectra, the significant height was calculated by

$$\bar{H}_{1/3} = 2.83\sqrt{\bar{E}},$$

where

$$\bar{E} = 2(\text{Variance}) = \text{area under power spectrum}$$

Table III and Figure 13 give the results of these computations. The results suggest that the meter may have responded accurately to both principle spectral bands. This is not in agreement with the analysis concerning the known input and its response from Section IV. However, Figure 13 is only suggestive because of the limited number of records taken.

The power spectra were compared to the reports from the Fleet Numerical Weather Central of the combined sea

	Number of Waves Observed	Visual $\overline{H}_{1/3}$ (feet)	Variance	Meter $\overline{H}_{1/3}$ (feet)
May 11	125	5.10	1.85	3.85
May 20	75	8.35	9.15	8.55
June 1	288	2.21	1.45	3.40
June 2	261	4.55	2.03	4.05

TABLE III

RESULTS FROM SIGNIFICANT HEIGHT ANALYSIS

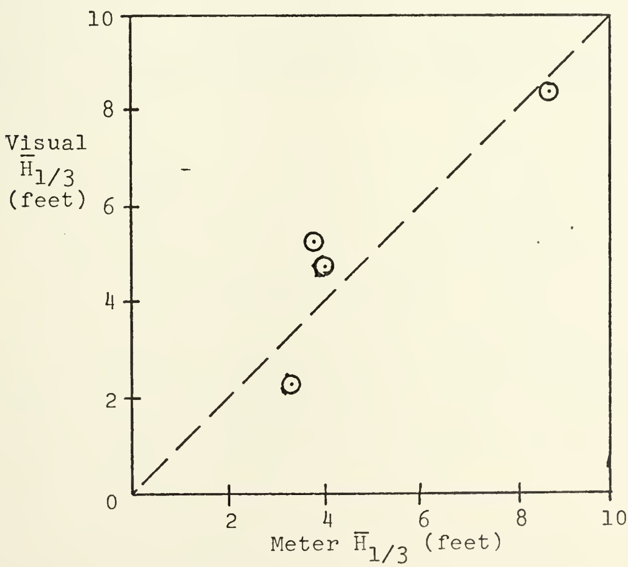

Figure 13. Eye Observations vs. Meter Observations of Significant Height

height, which gives contour lines representing significant sea height.

All the combined sea height analyses for the appropriate days indicate a significant height of approximately three feet in the vicinity of the mouth of Monterey Bay (Figures 14-17 in Appendix A). This roughly corresponds to all the reports except the one taken on the 20th of May. However, the combined sea height analysis may not be too reliable because it is based on a small number of reports for the area along the coast of California.

In addition, sea surface atmospheric pressure analyses were used to locate and investigate the generating areas of the dominant frequency bands for the swell recorded by the instrument. Taking the peak frequency from the power spectra, the group velocity of the dominant swell was computed using

$$c_g = \frac{1.5}{2f}$$

c_g = deep water group velocity in knots

f = peak frequency in sec^{-1}.

Then, the distance traveled by the dominant wave was computed by using the difference between the time of the sea surface pressure analysis and the time the wave record was taken. A line was drawn on each sea surface pressure analysis (Figures 18-21 in Appendix A) to represent the starting location for the swell observed at Monterey Bay. These lines appear to

lie in each case within the possible generating area of the dominant frequency swell.

Computations were also made to determine whether, according to a commonly used wave generation model, winds in these possible generating areas produced the recorded dominant frequencies. The geostrophic wind speed was calculated from the pressure field using

$$V_g = \left[\frac{1}{2\Omega\rho\sin\phi}\right]\frac{\Delta P}{\Delta N} = \frac{9.53}{\sin\phi}\frac{\Delta P}{\Delta N}$$

where

V_g = geostrophic wind speed in knots

Ω = angular velocity of earth

ϕ = latitude

ΔP = pressure difference in millibars

ΔN = latitude change (60 miles $\approx$ 1 degree of latitude)

The surface wind speed, V_s, is then approximated closely enough for present purposes by;

$$V_s = .8V_g$$

With values of surface wind speed and estimated fetch, the maximum periods which these generating areas were capable of producing was estimated by using co-cumulative spectra for wind speeds as a function of fetch, as given by Pierson, Neumann, and James [5]. In all four cases, the generating areas apparently were capable of producing the dominant frequency swell recorded by the meter. Table IV gives the results of the computations made.

TABLE IV

RESULTS FROM GENERATING AREA ANALYSIS

	Peak Freq. (sec^{-1})	Period (sec)	Travel Time (hrs.)	Miles Traveled	V_s (knots)	Fetch (miles)
May 11	.08	12.5	41	900	14.7	200
May 20	.11	9.1	35	550	8.2	200
June 1	.08	12.5	65	1940	9.4	200
June 2	.08	12.5	65	1940	13.0	200

Furthermore, the surface pressure analysis seemed to indicate that secondary peaks in the power spectra are due to local wind conditions. For example, it is noted that a large secondary peak not present on 1 June occurs at approximately .25 sec^{-1} on 2 June. From Section VI, it was recorded that there was a large increase in the wind over that 24 hour period. This suggests that the secondary peak was due to the local winds.

IX. CONCLUSIONS

The portable free floating wave buoy provides a relatively inexpensive method for gathering wave records. The evaluation of the records suggests that the main spectral bands, the swell and the local wind waves of the wave system, are properly resolved by the meter. However, further dynamic and static calibration is suggested in order to resolve the discrepancy in amplitude measurements between the input-response analysis and the significant height analysis. Comparison of the buoy's wave records with the simultaneously made records of well-calibrated wave meters on Flip would be a desirable future project. Also, further comparisons with weather analyses would be profitable in evaluation of the meter.

The portable nature and ease of operation of the free floating wave buoy provide the opportunity for deep water wave forecast verifications to be made by organizations which are financially limited. The meter permits records of deep water waves to be taken more quickly, easily, and cheaply than with most other existing deep water wave meters.

APPENDIX A

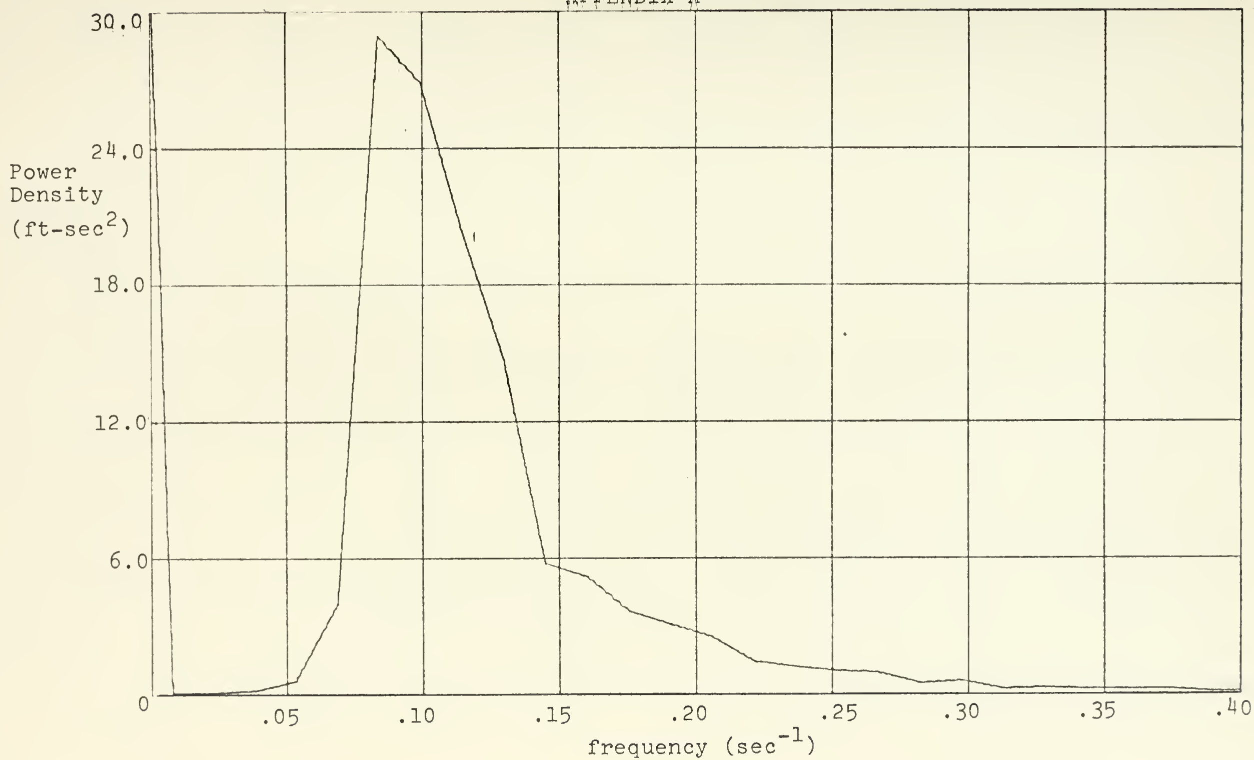

Figure 9. Spectral Wave Analysis ... 11 May 70
90% Confidence: $S_{5\%} = 1.5S$, $S_{95\%} = .71S$

Figure 10. Spectral Wave Analysis ... 20 May 70
90% Confidence: $S_{5\%} = 1.5S$, $S_{95\%} = .71S$

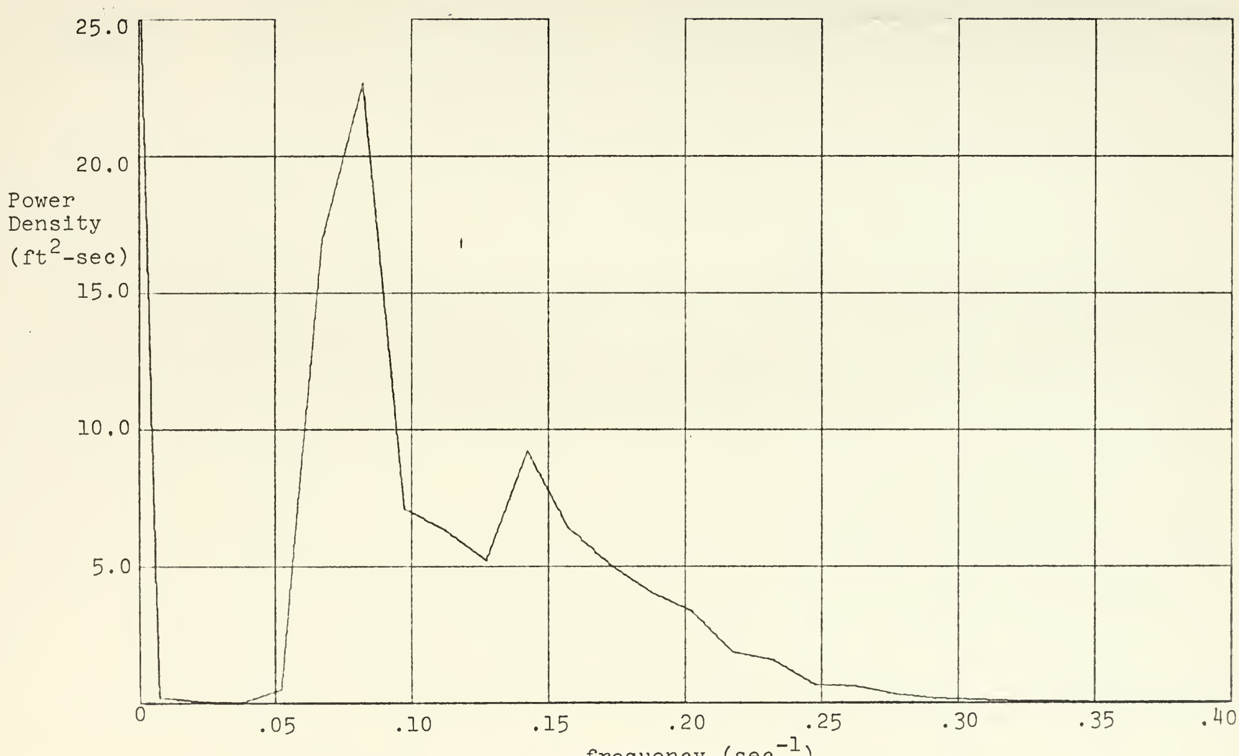

Figure 11. Spectral Wave Analysis ... 1 June 70
90% Confidence: $S_{5\%} = 1.5S$, $S_{95\%} = .71S$

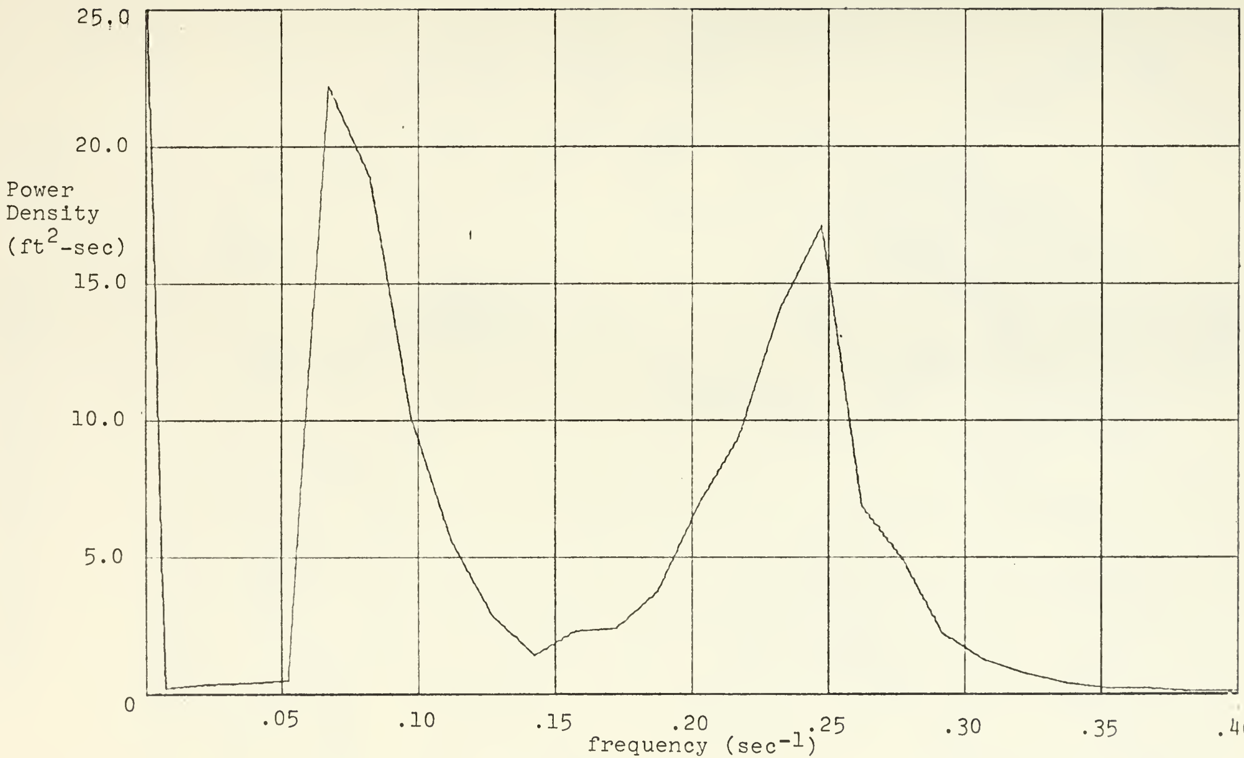

Figure 12. Spectral Wave Analysis ... 2 June 70

90% Confidence: $S_{5\%} = 1.5S$, $S_{95\%} = .71S$

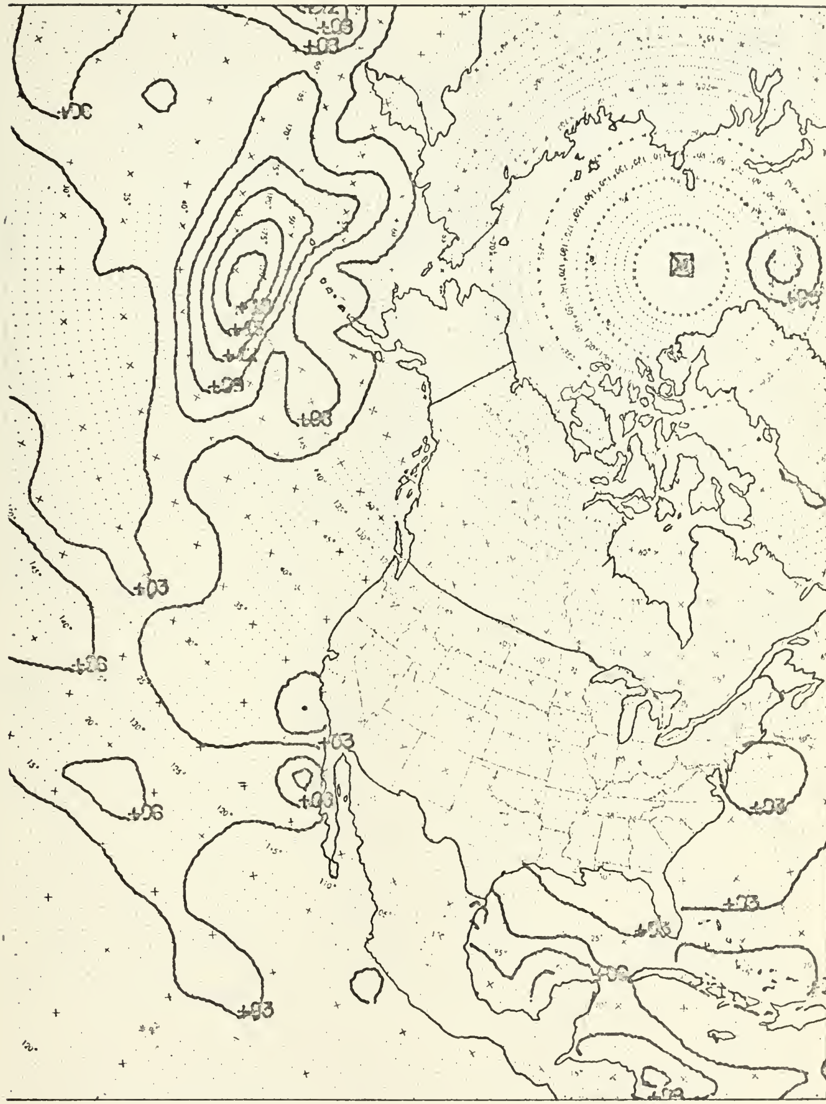

Figure 14. Combined Sea Height Analysis ...
00Z, 12 May 70

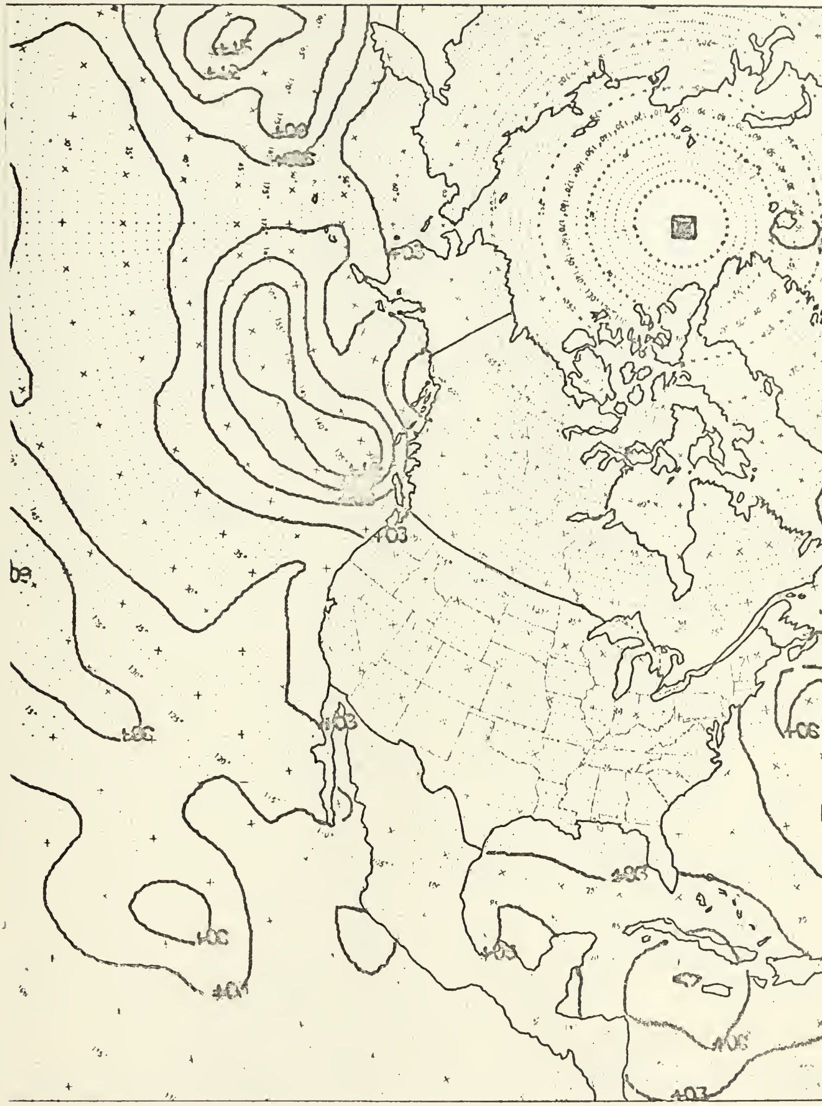

Figure 15. Combined Sea Height Analysis ...
00Z, 21 May 70

Figure 16. Combined Sea Height Analysis ...
00Z, 2 June 70

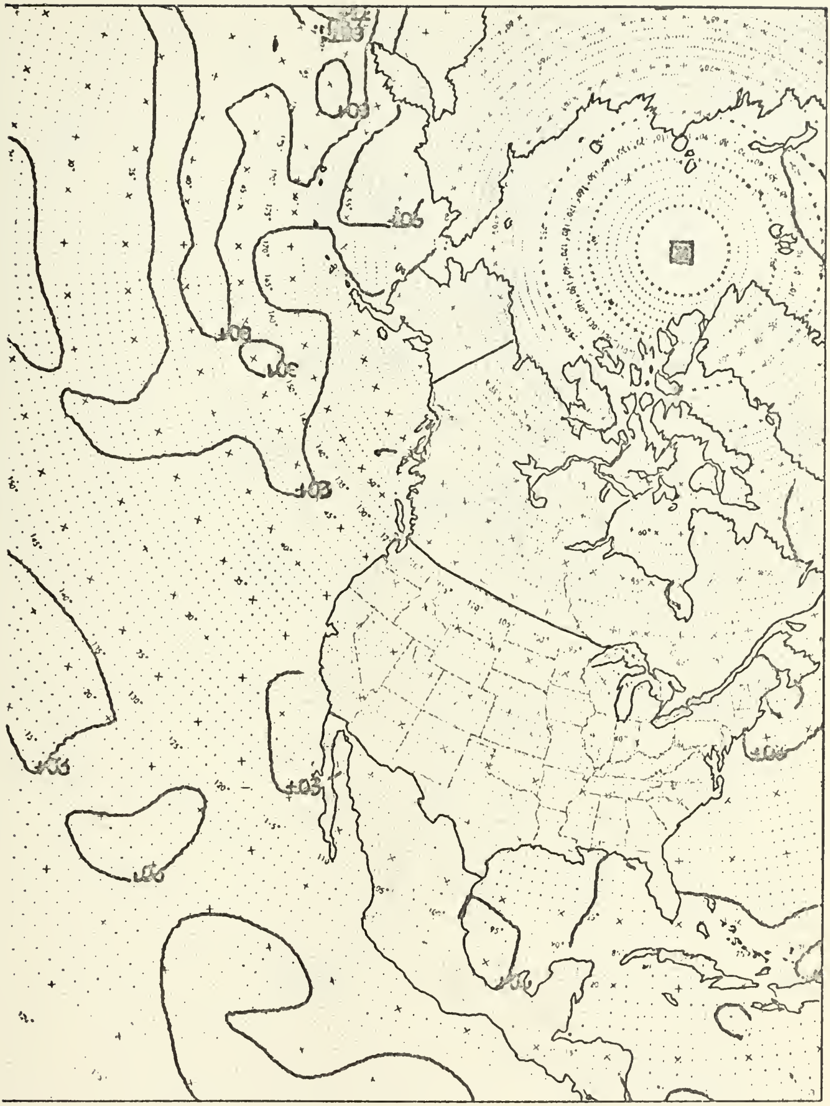

Figure 17. Combined Sea Height Analysis ...
00Z, 3 June 70

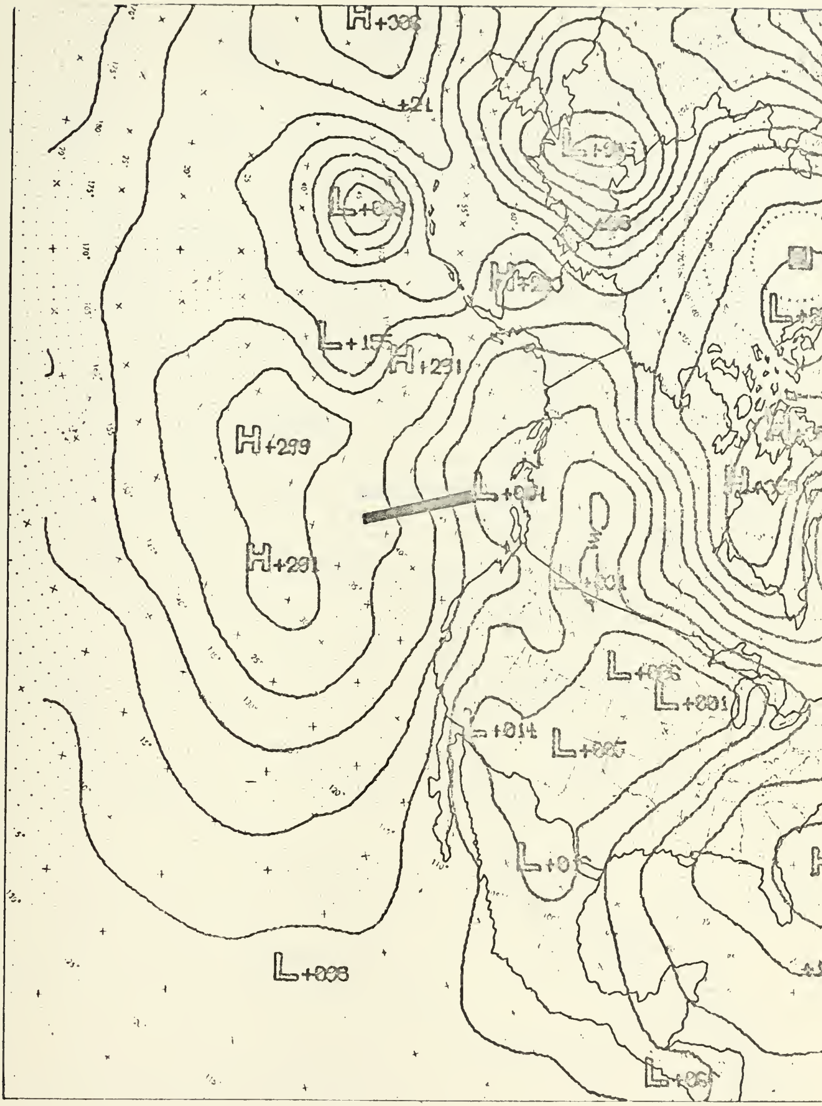

Figure 18. Sea Surface Pressure Analysis ...
00Z, 10 May 70

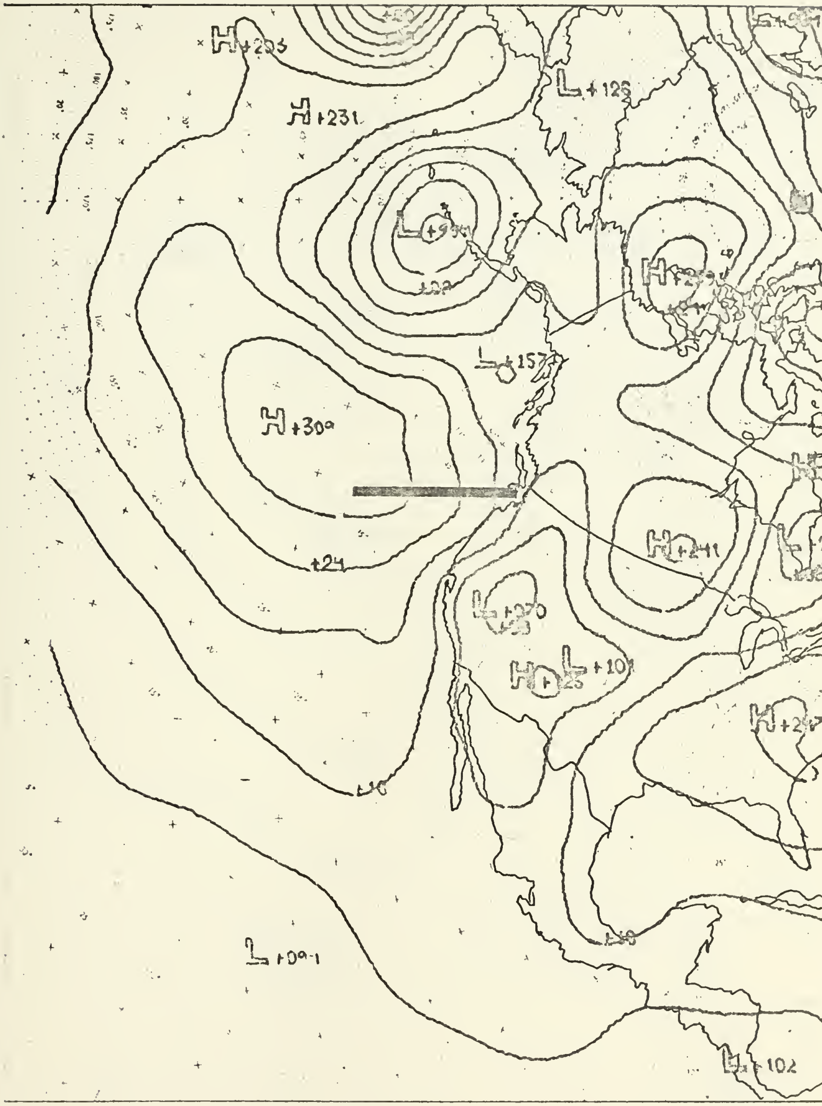

Figure 19. Sea Surface Pressure Analysis ...
06Z, 19 May 70

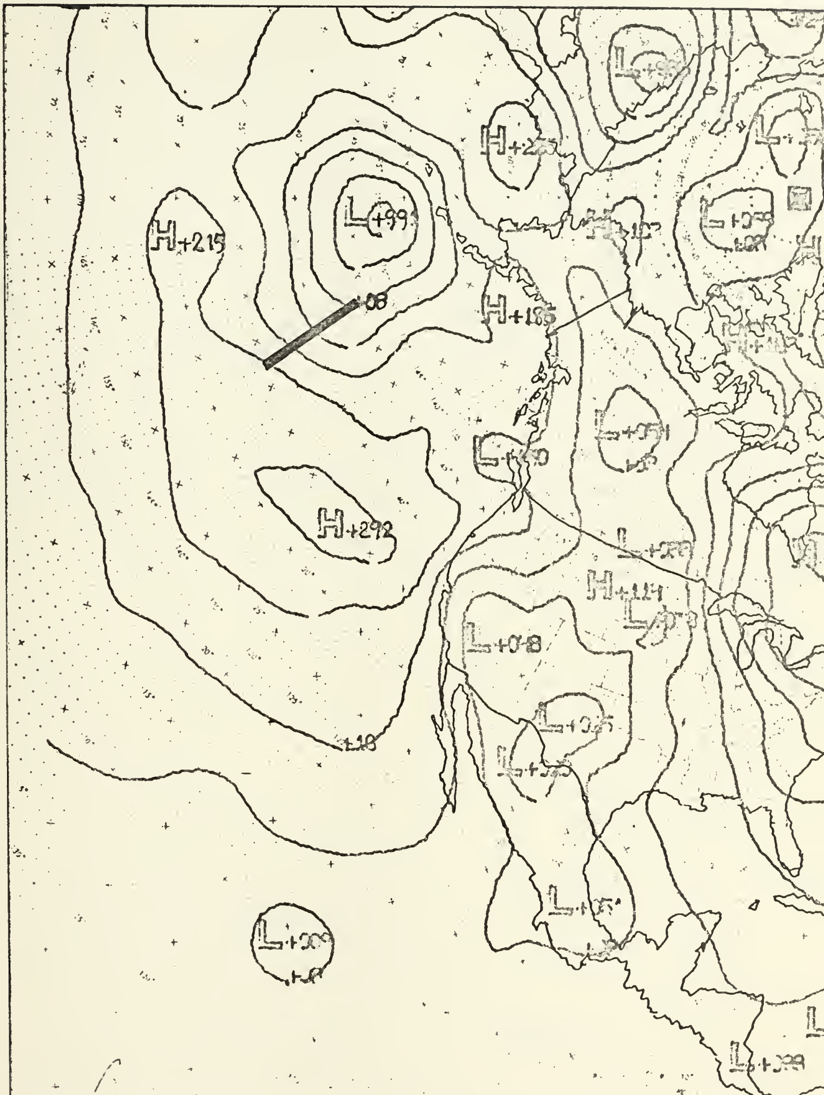

Figure 20. Sea Surface Pressure Analysis ...
00Z, 29 May 70

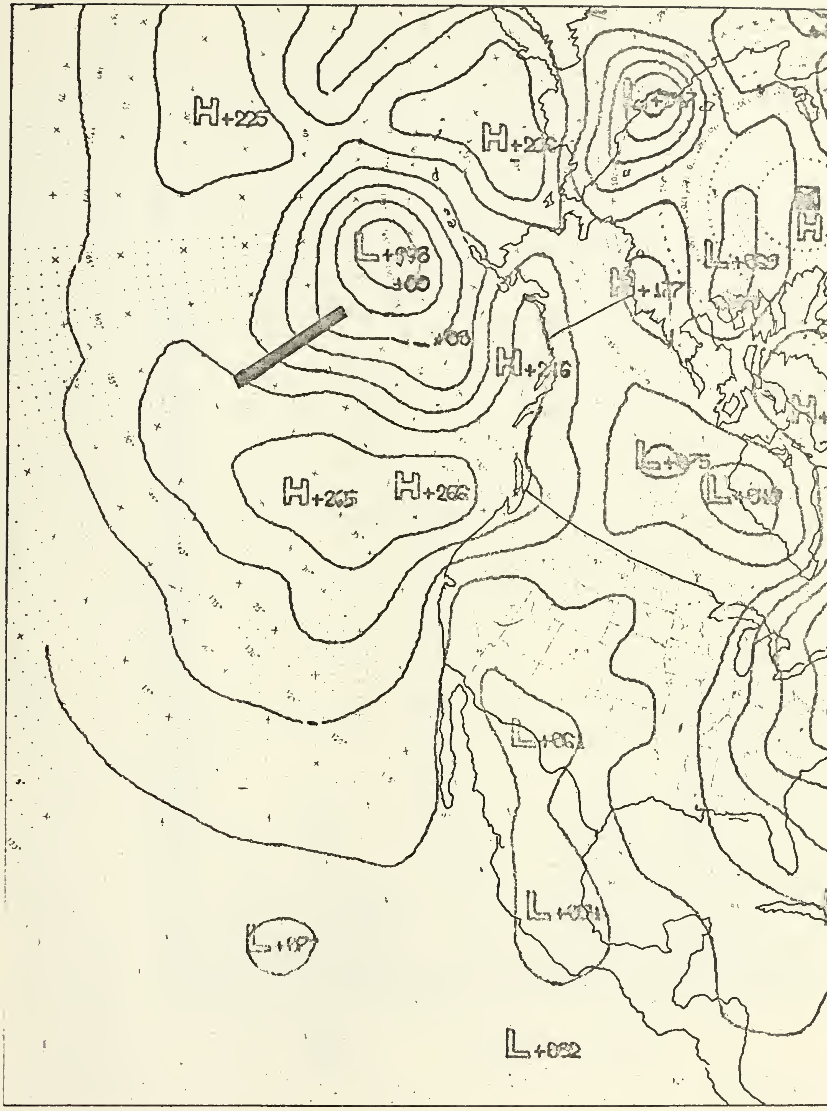

Figure 21. Sea Surface Pressure Analysis ...
00Z, 30 May 70

PROGRAM CONVERT

```
VBGA,T10000,CM155000. WAVE DIGIT.
RUN(S,,,,,,200000,,1)
REQUEST TAPE1,HI,X. INPUT
RFL,145000.
SETCORE(ZERO)
REDUCE.
LGO.
      PROGRAM CONVERT(INPUT,OUTPUT,PUNCH)
C     THIS PROGRAM CONVERTS THE DIGITIZED RECORD INTO PUNCHED CARDS.
      DIMENSION U(15000),V(15000),N(80),IBUFF(10000),NK(80)
C     NUMBER OF TAPES EQUALS L
      READ 97,L
   97 FORMAT(I2)
      DO 116 JJ=1,L
      DO 100 I=1,12500
      U(I)=0.0
  100 V(I)=0.0
  101 DO 202 I=1,10000
  202 IBUFF(I)=0
      COUNTX=0.0
      COUNTY=0.0
      NUM=10000
      M=1
      K8=0
      CALL LIOF(5LRBCD1,IBUFF,NUM,NPAR,NEOF)
      IF(NEOF) 602,200
  200 K=-7
      KF=0
  201 K=K+8
      KA=K+8
      KC=0
      DO 102 KB=K,KA
      KC=KC+1
      NK(KC)=IBUFF(KB)
  102 IF (NK(KC).EQ.0) KF=1
      DECODE(80,103,NK) (N(I),I=1,80)
  103 FORMAT(80R1)
      DO 104 I9=1,80
      IF(N(I9).EQ.50B) GO TO 106
      IF(N(I9).EQ.55B) GO TO 107
      IF(N(I9).EQ.34B) GO TO 108
      IF(N(I9).EQ.47B) GO TO 105
C     SYMBOL (50B) REPRESENTS AN INCREMENT TRAVEL IN THE MINUS X OR Y
C     DIRECTION BY THE DIGITIZER.
C     SYMBOL (55B) REPRESENTS A ZERO INCREMENT TRAVEL IN THE X OR Y
C     DIRECTION BY THE DIGITIZER.
C     SYMBOL (34B) REPRESENTS AN INCREMENT TRAVEL IN THE POSITIVE X
C     OR Y DIRECTION BY THE DIGITIZER.
```

```
C     SYMBOL (47B) IS A FLAG INSERTED IN THE RECORD BY THE PERSON DIGITIZING.
      GO TO 104
  105 PRINT 205,M,I9
  205 FORMAT(1H0,2I10)
      UF(M.GT.15000) GO TO 113
      GO TO 104
  106 RX=-0.01
      K8=K8+1
      GO TO 109
  107 RX=0.0
      K8=K8+1
      GO TO 109
  108 RX=0.01
      K8=K8+1
  109 K3=K8/2
      K3=2*K3
      IF(K3.EQ.K8) GO TO 111
      COUNTX=COUNTX+RX
      IF(COUNTX.NE.0.0) GO TO 110
      GO TO 104
  110 U(M)=COUNTX
      GO TO 104
  111 COUNTY=COUNTY+RX
      IF(COUNTX.NE.0.0) GO TO 112
      GO TO 104
  112 V(M)=COUNTY
      COUNTX=0.0
      M=M+1
      IF(M.GT.15000) GO TO 600
  104 CONTINUE
      IF(KF.EQ.1) GO TO 113
      GO TO 201
  113 MAX=M-7
      PRINT 215,(V(I),I=1,M)
      PUNCH 213,(V(I),I=1,M)
      PRINT 215,(U(I),I=1,M)
  215 FORMAT(1H ,10X,14F7.2)
  213 FORMAT(14F5.2)
  116 CONTINUE
      STOP
  600 PRINT 601
  601 FORMAT(1H1,20X,37H ***** U AND V SPACE INADEQUATE *****,)
  602 STOP 12345
      END
```

PROGRAM SPECTRUM

```
C      PROGRAM COMPUTES ONE DIMENSIONAL SPECTRAL ANALYSIS OF WAVE DATA
C      AND PLOTS RAW AND SMOOTH SPECTRUM
C      OUTPUTS ARE FR(I)=CPS AND B(I)=LENGTH**2/SEC
//     EXEC    FORTCLGP,REGION.GO=220K
//FORT.SYSIN DD *
       IMPLICIT REAL*4(A-H,O-Z)
       REAL*4 LABEL/4H    /
       REAL*8 ITITLE(12)
       DIMENSION E(8196),X(8196),INV(2048),S(2048),B(4098),FR(4098)
       DIMENSION P(1500)
       READ(5,100) (ITITLE(I),I=1,12)
  100  FORMAT(6A8)
C      READ NUMBER OF POINTS (N),SAMPLING INTERVAL (DEL),AND M WHERE N=2*2**M
       READ(5,300) N,DEL,M
  300  FORMAT(I5,F15.7,I5)
C      READ ORIGINAL WAVE AMPLITUDES(W/R TO DATUM LINE) E(I)
       READ(5,400) (E(I),I=1,N)
  400  FORMAT(14F5.2)
C      WRITE LAST HEIGHT READ (USED AS A DATA CHECK)
       WRITE(6,450) E(N)
  450  FORMAT('1',5X,F5.2)
       X(1)=0.0
       DO 500 I=1,N
       X(I+1)=X(I)+DEL
  500  CONTINUE
C      PRINT OUT ORIGINAL DATA
       J=1
       JJ=N/8
       DO 900 I=1,JJ
       K=J+7
       MM=J-1
       WRITE(6,600) MM
  600  FORMAT('0',5X,'TOTAL POINTS =',I5)
       WRITE(6,700) (X(L),L=J,K)
  700  FORMAT(' ',5X,'TIME(SEC)',3F13.3)
       WRITE(6,800) (E(L),L=J,K)
  800  FORMAT(' ',5X,'AMP(FEET)',8F13.3)
       J=J+8
  900  CONTINUE
C      COMPUTE DATA FOR SPECTRAL ANALYSIS AND SUBROUTINE RHARM
```

```
C     THIS SECTION ZERO FILLS AS NECESSARY
      IF(N.GE.8192) GO TO 975
      DO 950 I=N,8191
      E(I+1)=0.0
  950 CONTINUE
      N=8192
  975 T=(N-1)*DEL
      WRITE(6,1000) T,DEL,N
 1000 FORMAT('0',5X,'RECORD LENGTH ='F15.5,'SECONDS',5X,'SAMPLE INTERVAL
     1 =',F10.5,'SECONDS',5X,'DATA POINTS=',I5)
C     CALCULATE SPECTRUM
      CALL RHARM(E,M,INV,S,IFERR)
      NP=2**M-1
      DO 1100 I=1,NP
      J=2*I+1
      XC=E(J)**2
      K=J+1
      YC=E(K)**2
      L=I+1
      B(L)=T*(XC+YC)/4
 1100 CONTINUE
      B(1)=E(1)**2
      B(1)=T*B(1)
      NF=2**M+1
      B(NF)=E(N+1)**2
      B(NF)=B(NF)*T
C     CALCULATE FREQUENCY ARRAY
      DO 1200 I=1,NF
      XF=I-1
      FR(I)=XF/T
 1200 CONTINUE
      CALL DRAW(500,FR,B,0,0,LABEL,ITITLE,0.05,0.05,0,0,0,0,8,8,1,LAST)
C     PRINT TRANSFORMED ENERGIES AND FREQS
      WRITE(6,1300)
 1300 FORMAT(1H1,16X,'ONE DIMENSIONAL SPECTRUM'///,15X,'CPS',14X,'LENGTH
     1**2/SEC',///)
      WRITE(6,1350)  ((FR(I),B(I)),I=1,NF)
 1350 FORMAT(5X,1PE16.8,4X,1PE16.8)
C     NOW SMOOTH THE SPECTRUM BY SUMMING OVER INTERVALS OF 'Z' FREQ POINTS
      Z=5
      NI=2
      NL=Z+1
      SUMB=0.0
      J=2
 1400 DO 1450 I=NI,NL
      SUMB=B(I)+SUMB
 1450 CONTINUE
      B(J)=SUMB/Z
```

```
      SUMB=0.0
      NI=NL+1
      NL=NL+Z
      J=J+1
      JMAX=J
      IF(NL-NF) 1400,1500,1500
 1500 CONTINUE
      DO 1600 I=2,JMAX
      XI=I-2
      XF=(Z/2.0+0.5)+XI*Z
      FR(I)=XF/T
 1600 CONTINUE
C     CALL DRAW TO PLOT SMOOTH SPECTRUM
      CALL DRAW(200,FR,B,0,0,LABEL,ITITLE,0.05,0.05,0,0,0,0,8,8,1,LAST)
      WRITE(6,1700)
 1700 FORMAT(1H1,35X,'ONE DIMENSIONAL SMOOTHED SPECTRUM'///,25X,'CPS',
     114X,'LENGTH**2/SEC',5X,'PERIOD(MIN)',///)
      P(1)=0.0
      DO 1750 I=2,JMAX
      P(I)=1.0/(FR(I)*60.0)
 1750 CONTINUE
      WRITE(6,1800)  ((FR(I),B(I),P(I)),I=1,JMAX)
 1800 FORMAT(10X,3F20.5)
      STOP
      END
//GO.FT06F001 DD SPACE=(CYL,(5,1))
//GO.SYSIN DD *
```

SUBROUTINE RHARM

Given 2N real numbers, X_o, X_1 ... X_{2N-1}, the subroutine computes Fourier coefficients, a_o, a_1, b_1, a_2, b_2,... a_{N-1}, b_{N-1}, a_n in the equation

$$X_j = \frac{1}{2} a_o + \sum_{k=1}^{N-1} \left(a_k \cos(\frac{\pi jk}{N}) + b_k \sin(\frac{\pi jk}{N}) \right)$$

$$+ \frac{1}{2} a_N (-1)^j$$

where $j = 0, 1, \ldots 2N-1$

Therefore, with N inputs from a time series, output contains:

$$\frac{a_o}{2},\ b_o = 0,\ a_1,\ b_1,\ a_2,\ b_2,\ \ldots\ a_{N/2},\ b_N = 0$$

to get the power spectrum, Program Spectrum gives the spectral estimate, S, equal to:

$$\sum_{N=1}^{\frac{N}{2}+1} S_N = \sum_{k=2}^{\frac{\bar{N}}{2}+1} \left[\frac{a_k^2 + b_k^2}{4} \right] T$$

where T = record length.

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13. ABSTRACT

A free-floating wave meter was used to obtain a time series of wave-induced pressure variations in deep water. The meter's response was roughly checked against a piston-type pressure testing apparatus.

Techniques in the operation of the meter were developed involving a slight modification in the suspension of the sensor.

Power spectra of the pressure variations were obtained from the digitized wave record via the amplitude spectra given by the fast Fourier transform.

Characteristics of the power spectra of the metered waves were used to evaluate the meter by comparing them with the waves that might be anticipated (on the basis of theory) from the existing surface wind field and with visual observations of the metered waves.

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